A Comparison of the Multiscale Retinex With Other Image Enhancement Techniques

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Abstract

The multiscale retinex with color restoration (MSRCR) has shown itself to be a very versatile *automatic* image enhancement algorithm that simultaneously provides dynamic range compression, color constancy, and color rendition. A number of algorithms exist that provide one or more of these features, but not all. In this paper we compare the performance of the MSRCR with techniques that are widely used for image enhancement. Specifically, we compare the MSRCR with color adjustment methods such as gamma correction and gain/offset application, histogram modification techniques such as histogram equalization and manual histogram adjustment, and other more powerful techniques such as homomorphic filtering and 'burning and dodging'. The comparison is carried out by testing the suite of image enhancement methods on a set of diverse images. We find that though some of these techniques work well for some of these images, only the MSRCR performs universally well on the test set.

Introduction

The Multiscale Retinex[1] (MSR) is a generalization of the single-scale retinex[2−4] (SSR), which, in turn, is based upon the last version of Land's center/surround retinex[5]. The current version of the MSR combines the retinex dynamic range compression and color constancy with a color 'restoration' filter that provides excellent color rendition[6−8]. This version of the MSR is called the Multiscale Retinex with Color Restoration (MSRCR). The MSRCR has been tested with a very large suite of images and has consistently proven to be better than any conventional image enhancement technique. In this paper we present a comparison of the MSRCR with several of the most popular image enhancement methods. These include point transforms such as automatic gain/offset, non-linear gamma correction, non-linear intensity transforms such as the logarithmic transform or the 'square-root' transform; and global transforms such as histogram equalization[9], homomorphic filtering[10], and manual 'burning and dodging.'

State-of-the-art Techniques

In this section we briefly describe the characteristics of some of the state-of-the-art techniques most commonly used for image enhancement.

Gain/offset correction

One of the most common methods of enhancing an image is the application of a gain and an offset to stretch the dynamic range of an image. This is a linear operation and hence has limited success on scenes that encompass a much wider dynamic range than that that can be displayed. In this case, loss of detail occurs due to saturation and clipping as well as due to poor visibility in the darker regions of the image. For a scene with dynamic range between r_{max} and r_{min}, and a display medium with dynamic range d_{max}, this transform can be represented by

$$I_i'(x,y) = \frac{d_{max}}{r_{max} - r_{min}} \cdot (I_i(x,y) - r_{min}), \qquad (1)$$

where I_i is the ith input band, and I_i' is the ith output band. This particular transform will transform the scene to completely fill the dynamic range of the display medium. This does not imply, however, that this process will provide a good visual representation of the original scene.

Non-linear Point Transforms

Another well known method used for providing dynamic range compression is the application of non-linear transforms such as the gamma non-linearity, the logarithm function, and the power-law function to the original image. These functions are typically biased toward increasing the 'visibility' in the 'dark' regions by sacrificing the visibility in the 'bright' areas. The output of such filters can be described by

$$I_i'(x,y) = P\left[I_i(x,y)\right], \qquad (2)$$

where $P[\,]$ represents the point non-linearity. A typical point non-linearity is illustrated in Fig. 1.

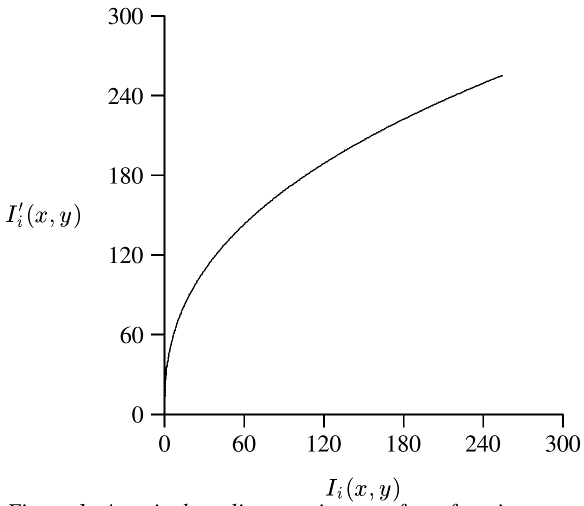

Figure 1: *A typical nonlinear point transform function.*

Histogram Equalization

A global technique that works well for a wide variety of images is histogram equalization. This technique is based on the idea of remapping the histogram of the scene to a histogram that has a near-uniform probability density function. This results in reassigning dark regions to brighter values and bright regions to darker values. Histogram equalization works well for scenes that have unimodal or weakly bi-modal histograms (i.e. very dark, or very bright), but not so well for those images with strongly bi-modal histograms (i.e. scenes that contain very dark and very bright regions).

Homomorphic Filtering

The technique that most resembles ours conceptually and functionally is homomorphic filtering[10]. The general idea of homomorphic filtering is shown in Fig. 2. The image is first passed through a logarithmic non-linearity that provides dynamic range compression. It is then Fourier transformed, and its representation in the spatial frequency domain is modified by applying a filter that provides contrast enhancement. The modified image is then inverse Fourier transformed and is passes through an exponential non-linearity that 'reverses' the effects of the logarithmic nonlinearity.* Mathematically,

$$
\begin{aligned}
s_i(x,y) &= \ln[I_i(x,y)] && (3)\\
s_i'(\upsilon,\omega) &= \mathcal{F}[s_i(x,y)] && (4)\\
s_i''(\upsilon,\omega) &= s'(\upsilon,\omega)\mathcal{H}(\upsilon,\omega) && (5)\\
s_i'''(x,y) &= \mathcal{F}^{-1}[s_i''(\upsilon,\omega)] && (6)\\
I_i'(x,y) &= \exp[s_i'''(x,y)], && (7)
\end{aligned}
$$

where $\mathcal{F}[\,]$, and $\mathcal{F}^{-1}[\,]$ represent the Fourier and the inverse Fourier transforms respectively, and $\mathcal{H}$ represents the homomorphic filter. It is in its final exponential transform that the homomorphic filter differs the most from the MSRCR. MSRCR does not apply a final inverse transform to go back to the original domain!

Manual Image Enhancement

As both professional and amateur photographers face the limitations of the narrow dynamic range in current printing technology, and the inadequate performance of image enhancement algorithms, more and more attention is being focused on manual enhancement methods. One such technique is 'burning-and-dodging' where different regions of an image are interactively modified by a user†. The burn and dodge tool provides the capability of modifying the color content of a region by using tools of varying sizes and shapes that work as electronic "scrims."

Multiscale Retinex with Color Restoration

The general form of the MSRCR can be summarized by the following equation:

$$
\begin{aligned}
\mathcal{R}_{M_i}(x,y) = \sum_{s=1}^{S} w_s(\log\left[I_i(x,y)\right] - \\
\log\left[I_i(x,y) * M_s(x,y)\right]),\ \ i = 1,...,N
\end{aligned}
\quad (8)
$$

where $\mathcal{R}_{M_i}$ is the ith band of the MSRCR output, S is the number of scales being used, w_s is the weight of the scale, I_i is the ith band of the input image,, and N is the number of bands in the input image. The surround function M_s is defined by

$$M_s(x,y) = K\exp\left[\sigma_s^2/(x^2+y^2)\right],$$

where σ_s is the standard deviation of the sth surround function, and $\iint K\exp\left[\sigma_s^2/(x^2+y^2)\right]\,dx\,dy = 1$. The number of scales, S, and the widths of the surround functions, σ_s, are image independent‡. In other words, these have been chosen to maximize enhancement for a large§ number of images. Once the constants have been selected, then the process is truly automatic and independent of the variations in scene statistics.

*A modified color version of the homomorphic filter was proposed by Faugeras[11] in 1979. Our implementation simply applies the black and white version of the homomorphic filter to each band of the color image and combines the results to form a color output image.

†Adobe Photoshop 4.0, a commercial photo manipulation software package, provides a burn and dodge tool.

‡Typically for 512×512 images. The σ_s may change with the dimension of images.

§We have not yet found an exception after having processed 1000+ images!

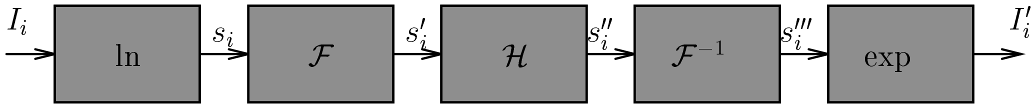

Figure 2: *Homomorphic filtering*[9]

Comparison

We have compared the MSRCR with all of the image enhancement techniques described above. We present the results in Figs. 3, and 4. We present the comparison with manual burning and dodging separately.

Point operations

Figure 3 shows a collage of images that compares the output of the MSRCR with the point transforms. As can be seen, the MSRCR provided the best overall visual quality in each case. The techniques such as histogram equalization perform well for a wide range of scenes, but they also fail for a large set. The MSRCR outperforms the other methods universally.

Homomorphic filtering

Figure 4 shows a comparison of the MSRCR with homomorphic filtering. The homomorphic filter consistently provided excellent dynamic range compression but is lacking in final color rendition. The output of the homomorphic filter in effect appears extremely hazy compared with the output of the MSRCR though the dynamic range compression of the two methods appears to be comparable.

Manual Burning and Dodging

Figure 5 shows a comparison of the MSRCR with the results obtained by using manual burning and dodging. The manually processed image shows an improvement over the original as far as the information and detail in the dark areas is concerned but it lacks the vividness and color saturation that the MSRCR image retains and even enhances. There is obvious streaking from the very local operation of the tool stroke—this could be eliminated but only at the expense of adding considerably to the total processing time. In the high detail areas where there are sharp differences in reflectance, a tool with size approaching that of a single pixel would be required to bring out all the details. Since the time needed for enhancing a region is roughly in inverse proportion to the size of the tool being used for the processing, this suggests that a very large amount of time would be needed to perform such an enhancement. On a scene-by-scene basis, the time and effort required for manual manipulation can be reasonable; but the MSRCR produces images that are equivalent or better in quality at a fraction of the time. Because the visual quality of manual burning and dodging is solely limited by the patience and time commitment of the user, the case shown is perhaps typical of the performance achieved by the persistent non-specialist.

Conclusions

We have provided a brief description of the most commonly used image enhancement techniques and compared their operation with the multiscale retinex with color restoration. We have shown that the MSRCR outperforms these techniques in all cases in terms of dynamic range compression achieved, and the rendition of the final color image. The automatic nature of the process also enables us to use the same set of parameters 'blindly' for each and every image that is encountered. Of course, there are a few images for which the MSRCR has sub-par performance. But these are fairly rare and generally relate to defects in the original image data—such as preferential clipping of a spectral band. We are currently investigating methods to detect such scenes and adaptively adjust the MSRCR to correct for these sub-par performances.

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Figure 3: *A comparison of the MSRCR with point operations. Top row: original; second row: histogram equalization; third row: gain/offset; fourth row: gamma non-linearity; bottom row: MSRCR*

(a) Original (b) Homomorphic filter (c) MSRCR

Figure 4: *A comparison of the MSRCR with images enhanced by homomorphic filtering. The dynamic range compression achieved by the two methods is comparable, but the MSRCR produces images that possess much better contrast and sharper colors.*

(a) Original (b) Manual burning and dodging (c) MSRCR

Figure 5: *Comparison of the MSRCR with manual 'burning-and-dodging.' The manually enhanced image was produced using the burning and dodging tool provided in Adobe Photoshop 4.0. Circular tools with soft edges were used to modify the color content of different regions. The total time to produce this enhanced image was 20 minutes. The MSRCR image took 45 seconds on a PentiumPro 200MHz machine.*

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